Feasibility of the Sabatier reaction for use on the mars project

Assumptions:  
The Sabatier reactor has a conversion of 94% based on hydrogen (Zubrin, Mason and Price)  
0.84 kg of O2 are required per person per day.  
1 kg of CO2 is produced per person per day from respiration.  
 Nitrogen could be assumed to be solely a buffer gas (not be used up).  
Mission length is assumed to be 18 months with each month consisting of 31 days to allow for some safety.  
Number of persons on the trip is equal to 10.  
Cost of transporting 1kg to Mars is £1,000,000.  
For simplicity the composition of air is assumed to be 79% N2 and 21% O2 on a mass basis as well as a molar basis.

Design basis

The design basis is used to compare the cost of use of the Sabatier process (to recycle gases) with the cost of bringing all the gas required to Mars on every resupply mission.

Oxygen required for total trip = 18\*31\*0.34\*10 = 4687.2 kg

Incurring a cost of £4687.2 x10^6 or about £4.7 billion for oxygen transportation alone.

Any savings in the price of gas transportation are obviously very desirable judging from the cost of solely resupplying oxygen.

The Sabatier reaction can allow for recycling of waste CO2 (and in phase 3, use of CO2 on the planet) to provide the oxygen required.

The Sabatier reaction: CO2 + 4H2 🡪 CH4 +2H2O.

This will require shipping hydrogen to Mars as some will be lost unless it is recovered from CH4.

Mass and mole balances

Initially if we assume 100% conversion:

|  |  |  |  |
| --- | --- | --- | --- |
| Molar basis | kmol | Mass basis | kg |
|  |  |  |  |
| CO2 | 0.227272727 | CO2 | 10 |
| H2 | 0.909090909 | H2 | 1.818181818 |
| CH4 | 0.227272727 | CH4 | 3.636363636 |
| H2O | 0.454545455 | H2O | 8.181818182 |

Therefore at 94% H2 conversion the mass balance would be:

|  |  |  |  |
| --- | --- | --- | --- |
| Molar Basis | kmol | Mass basis | kg |
|  |  |  |  |
| CO2 | 0.227272727 | CO2 | 10 |
| H2 | 0.909090909 | H2 | 1.818181818 |
| CH4 | 0.213636364 | CH4 | 3.418181818 |
| H2O | 0.427272727 | H2O | 7.690909091 |
| H2 in product | 0.054545455 | H2 in product | 0.109090909 |
| CO2 in product | 0.013636364 | CO2 in product | 0.6 |

By separating CO2 and H2 from the methane (membranes, Pressure swing adsorption or cryogenic distillation could be used) the gases can be recycled for use in the process again.

The H2O is separated from the products by use of a condenser and electrolysed to produce pure hydrogen and oxygen.

The electrolysis reaction is given by 2H2O 🡪 2H2 +O2.

Using the 94% H2 conversion balance above the mass balance for electrolysis is given below:

|  |  |  |  |
| --- | --- | --- | --- |
| Molar basis | kmol | Mass Basis | kg |
|  |  |  |  |
| H2O | 0.427272727 | H2O | 7.690909091 |
| H2 | 0.427272727 | H2 | 0.854545455 |
| O2 | 0.213636364 | O2 | 6.836363636 |

As stated earlier the station needs to have at least 8.4 kg of O2 produced per day. The current specifications indicate a O2 deficit of (8.4 -6.836) = 1.536 kg per day.

Hydrogen is also consumed in the Sabatier reaction (in the production of methane) and unless a reactor is designed to crack the methane to produce hydrogen, this will also have to be imported to mars.

The hydrogen deficit is (1.82 –(0.855+0.11)) = 0.855 kg per day.

The total gas that would have to be transported to Mars would then be =18\*31\*(1.536+0.855)

= 1334.178 kg

The cost of bringing this gas to Mars would be = £ 1334.178 x 10^6  
or £ 1.33 billion.

This offers savings of approximately £3.4 billion on a normal supply mission. Other decisions could affect this value such as the decision to transport more nitrogen or extra gas supplies just in case.

**References**

1. R. Zubrin, L. Mason, and S. Price, "Mars Sample Return with In-Situ Resource Utilization; Phase I Final Report." Presented to NASA JSC Nov. 30, 1a993.